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ORIGINAL ARTICLE

Tea consumption and the risks of osteoporosis and hip fracture: a population-based longitudinal follow-up study

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Abstract

Summary This population-based longitudinal follow-up study showed a protective effect of tea consumption against osteoporosis, particularly among women and middle-aged people. High tea consumption was also associated with a reduced risk of hip fracture.

Introduction To investigate the association of tea consumption with the risks of osteoporosis and hip fracture.

Methods This study used the Keelung Community-based Integrated Screening database and Taiwan's National Health Insurance Research Database. A total of 42,742 subjects aged 45 to 74 years were enrolled. Each was classified as no tea consumption, low tea consumption, and high tea consumption, according to the results of an eating habits questionnaire. The diagnosis of osteoporosis and hip fracture was based on BMD measured by dual-energy X-ray absorptiometry and the X-ray findings. The median follow-up time was 8.5 years.

Results As compared with the no tea consumption group, the osteoporosis HRs for the low tea consumption and high tea consumption groups were 0.88 (95% confidence interval (*CI*) 0.80–0.96) and 0.87 (95% *CI* 0.80–0.94), respectively. Among those participants aged 59 or below, the osteoporosis HRs for low tea consumption and high tea consumption (vs. no tea consumption) were 0.85 (95% *CI* 0.74–0.96) and 0.79 (95% *CI* 0.69–0.90). The HRs of hip fracture for the low tea consumption and high tea consumption groups (vs. no tea consumption) were 0.85 (95% *CI* 0.67–1.08) and 0.69 (95% *CI* 0.55–0.86), respectively.

Conclusion Tea consumption was linked to a lower risk of osteoporosis, particularly among women and middle-aged people. High tea consumption was also associated with a reduced risk of hip fracture.

Keywords Fracture · Osteoporosis · Population-based study · Risk factors · Tea

Introduction

Osteoporosis is a chronic metabolic bone disease characterized by decreased bone mineral density (BMD) and deterioration of bony microarchitecture, resulting in bone fragility and greater susceptibility to fragility fractures [1]. Among fragility fractures, those of the hip have the most severe consequences, including significant morbidity and mortality, and increased socioeconomic and public-health burdens [2, 3].

Tea and tea-extract flavonoids, such as catechins, thearubigins, and theaflavins, have osteoprotective effects on bone biology because of their antioxidant and anti-inflammatory properties [4–6]. In animal-model studies, tea and tea-extract flavonoids have been found to protect against bone loss and microstructural deterioration, resulting in enhanced BMD and bone strength [7–9]. Most previous observational studies

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have also concluded that tea consumption had a positive effect on BMD [10, 11]. Although research on animal and human subjects has demonstrated that tea intake has a beneficial effect on bone health, previous studies have yielded inconsistent associations between tea consumption and the risk of hip fracture. Some prospective cohort studies have reported a null association between tea consumption and such risk [10, 12, 13], and other cohort studies have reported that tea consumption reduced such risk [14, 15]. Among the few cohort studies that simultaneously investigated the effects of tea intake on osteoporosis and hip fractures, the results were also inconsistent. Chen et al. showed that tea intake in postmenopausal women was positively associated with BMD, but tea intake had no significant impact on fracture risk [10]. Conversely, Myers et al. enrolled women aged more than 75 years and found that tea intake was not positively associated with hip BMD, but that — when high — it was associated with lower risks of osteoporotic fractures [15]. Moreover, because those two studies only recruited postmenopausal or older women, the interrelationship of tea consumption, osteoporosis, and hip fractures in men and middle age women remains unclear. As the associations between tea consumption and the risk of osteoporosis and hip fracture in men and middle age women are relatively under-studied, we therefore conducted this population-based, longitudinal follow-up study to investigate the impact of tea consumption on the risk of osteoporosis and hip fracture to help fill those gaps.

Materials and methods

Data sources

This study's cohort was drawn from individuals who took part in the Keelung Community-based Integrated Screening (KCIS) project, which has been conducted by the Health Bureau of Keelung City, Taiwan, since the beginning of 1999 [16]. The KCIS project initially intended to screen for five types of cancer (cervical, breast, colorectal, oral cancer, and hepatocellular carcinoma) and three chronic diseases (hypertension, diabetes, and hyperlipidemia). Data on demographic characteristics and lifestyle habits — smoking, alcohol consumption, physical activity, diet, etc. — were collected using a structured questionnaire. The details of the KCIS database have been described in previous studies [16, 17]. By the time our study commenced, KCIS had screened and collected data on 109,425 people.

The present study used the KCIS data from 2005 to 2012 and linked them to Taiwan's National Health Insurance (NHI) research database (NHIRD) and to the Mortality Registry from 2000 to 2015, both of which were found within the Health and Welfare Data Science Center database at National Taiwan University's Health Data Research Center (HDRC). Taiwan's National Health Insurance program is a single-payer, compulsory social insurance program, and the NHIRD covers more than 99% of the country's population. Therefore, by linking these databases, a large-scale representative sample was assembled for analysis.

Study subjects and design

We implemented a longitudinal follow-up study to investigate the impact of tea consumption on osteoporosis and hip fracture. We used the weekly frequency of tea consumption to classify the KCIS-screened subjects into three groups — no tea consumption (NTC), low tea consumption (LTC), and high tea consumption (HTC), such frequency-based classification of tea consumption has been used in previous research [18]. The information on tea consumption was obtained according to the answers the participants had provided on KCIS-administered eating habits questionnaire, which is part of the structured questionnaire in KCIS project. The types of tea in the eating habits questionnaire included green tea, black tea, oolong tea, and other types of tea. Specifically, those answers had been provided on a five-point scale, with 1 = seven times/week or more, 2 = five to six times/week, 3 = three to four times/week, 4 = one or two times/week, and 5 = rarely or never. Our NTC group was defined as subjects who answered "5," our LTC group as those who answered "3" or "4," and our HTC group as those who answered "1" or "2." Further details of the recruitment process for each group are shown in Fig. 1.

The inclusion criteria for subjects were (1) that they had tea-drinking data from their first screening in KCIS database between 2005 and 2012, which was defined as the index date; and (2) that they were between 45 and 74 years old on their respective index dates. Based on these criteria, a total of 45,667 subjects were included at this stage. Then, after linking these individuals' screening information from the KCIS database to their medical information from the NHIRD, we excluded subjects who had been diagnosed with osteoporosis (International Classification of Diseases, Ninth Revision, Clinical Modification, [ICD-9-CM] code 733.0) or hip fracture (ICD-9-CM code 820) within 1 year before their index dates, and therefore, we can identify newly diagnosed osteoporosis and hip fracture cases as the outcome events during the follow-up. The diagnosis of osteoporosis in Taiwan's NHI is made by physicians based on BMD measured by dual-energy X-ray absorptiometry. A T-score of less than −2.5 is defined as osteoporosis. The diagnosis of hip fracture is made by doctors based on the X-ray findings. After excluding 1332 subjects with a history of osteoporosis or hip fracture, 44,335 subjects were left.

Based on consideration of the risk factors for osteoporosis and/or hip fracture, we adjusted our analysis model

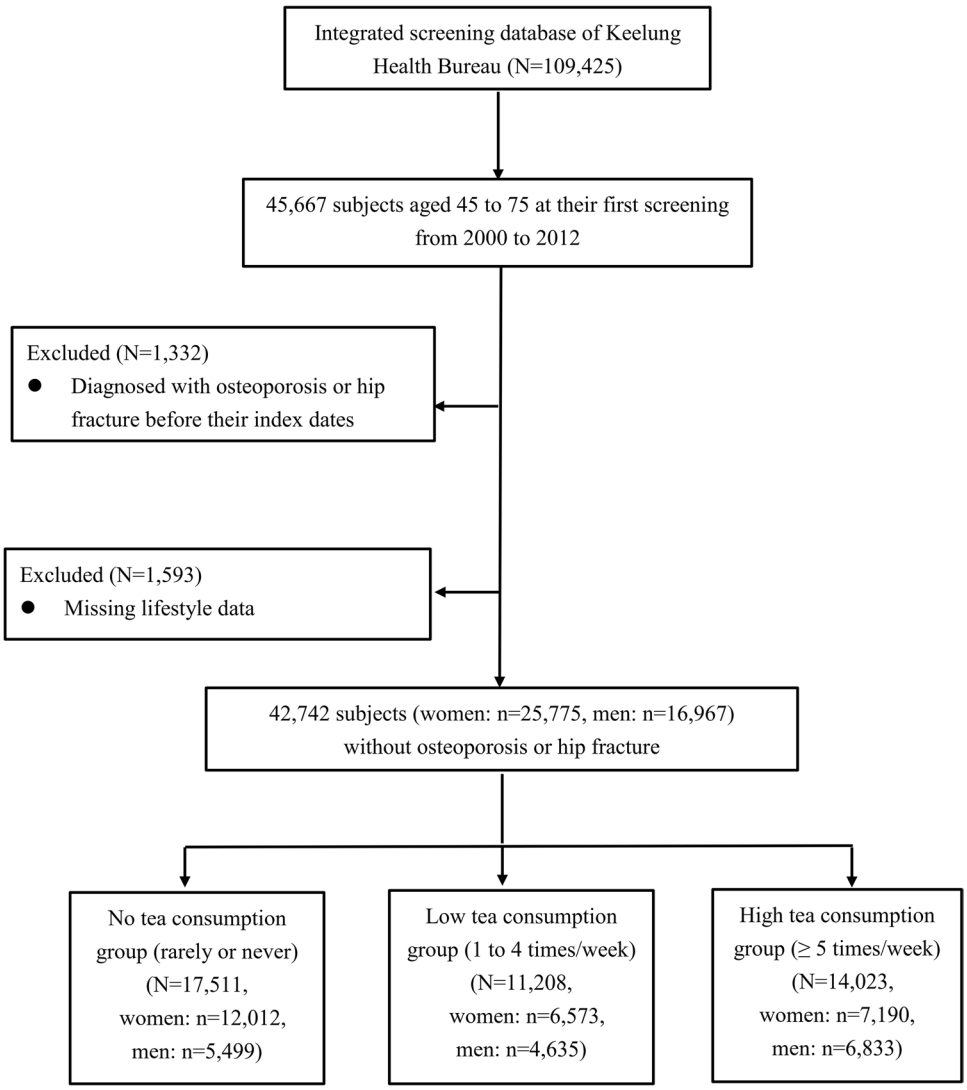

Fig. 1 Flowchart illustrating the enrollment process of the study population

by incorporating a range of relevant comorbidities, demographic factors, and lifestyle factors [19, 20]. NHIRD medical records were used as the source of data on these comorbidities, which included cancer (ICD-9-CM codes 140–208), diabetes (ICD-9-CM code 250), hyperlipidemia (ICD-9-CM code 272), hypertension (ICD-9-CM codes 401–405), coronary heart disease (ICD-9-CM codes 410–414 and 429.2), and stroke (ICD-9-CM codes 430–438). Given comorbidity was deemed to have been present if the patient had at least one hospital discharge or two outpatient visits with the relevant diagnosis code(s) within 12 months before his/her index date.

The demographic and lifestyle factors included sex, age, body mass index (BMI, calculated with weight in kilograms divided by height in meters squared), smoking, alcohol consumption, education level, and physical activity (PA). The information on lifestyle factors and tea consumption was obtained simultaneously using a structured questionnaire in the KCIS project. Based on the weekly PA time, we categorized the subjects into three PA groups as in our previous publication [21]: (1) a no PA group, comprising subjects who answered "Never" to the PA question; (2) a low PA group, consisting of subjects whose weekly PA times were less than 90 min; and (3) a high PA group, which included subjects whose weekly PA times were 90 min or more. We chose 90 min as the cut-off point between low PA and high PA because a prior population-based study in Taiwan showed that 90 min a week of PA reduced mortality from all causes [22].

The questionnaire used to collect education level classified it as "lower" if they had only attended elementary school; "median" if they had been to junior or senior high school; and "higher" if they had attended a university and/or other tertiary institution. Missing lifestyle data led to the exclusion of a further 1593 subjects, leaving a final

sample of 42,742 (NTC, $n = 17,511$; LTC, $n = 11,208$; HTC, $n = 14,023$).

Ethics statement

The present study was approved by the National Taiwan University Hospital Research Ethics Committee (NTUH-REC No.: 201802004RIND). This study analyzed existing data from the Keelung Community-based Integrated Screening database and Taiwan's National Health Insurance Research Database. To protect privacy, all identification numbers linked to information about individuals in the two databases were encrypted before data processing. Additionally, the health data used in this study could only be accessed in an access-controlled, privacy-protected room within the HDRC. Accordingly, the present study used pre-existing de-identified data released for research purposes; the requirement for informed consent was waived.

Occurrence of osteoporosis and hip fracture

The primary outcome of this study was newly diagnosed osteoporosis or hip fracture. The subjects were tracked from their index dates to either the first occurrences of osteoporosis or hip fracture, or if there were no such occurrences, to the end of 2015. Newly diagnosed osteoporosis was indicated by at least one inpatient discharge or two outpatient visits with ICD-9-CM code 733.0, and newly diagnosed hip fracture, by at least one inpatient discharge with ICD-9-CM code 820 during follow-up. The occurrence of a second hip fracture was not included as an outcome event.

Statistical analysis

All analyses were performed using SAS version 9.4 software (SAS Institute, Cary, NC). We examined inter-group differences in the demographic, lifestyle, and comorbidity variables using chi-square testing and analysis of variance (ANOVA). The incidence rate was calculated as the number of osteoporosis or hip-fracture events in a tea group, divided by the total follow-up time of that group (per 1000 person-years). Cox proportional-hazard regression was then applied to estimate the effect of tea-group membership on each of the two target medical conditions. Also, because the association of tea consumption with osteoporosis might vary by sex or age, we used stratified analysis to account for those factors separately. All p values reported are 2-sided, and the significance level was set at < 0.05.

Results

Table 1 shows the baseline characteristics of women. There were significant inter-group differences in age, body mass index (BMI), lifestyle factors, and comorbidities (diabetes, hypertension, hyperlipidemia, coronary heart disease, stroke, and cancer) among the NTC, LTC, and HTC groups in women. The baseline characteristics of men are presented in Table 2. There were notable inter-group differences in age, BMI, lifestyle factors, and comorbidities (hypertension, hyperlipidemia, coronary heart disease, and stroke) among the NTC, LTC, and HTC groups in men. The median follow-up time was 8.5 years, with an interquartile range of 3.3 years.

Risk of osteoporosis

The number of osteoporosis events and hazard ratio of osteoporosis for the three groups is presented in Table 3. During the follow-up period, 3278 cases of osteoporosis were identified. Our analytical results showed that the LTC and HTC groups both had a significantly lower risk of developing osteoporosis than the NTC group.

Table 3 also showed the sex-stratified and age-stratified HRs for osteoporosis for the three tea-consumption groups. In the sex-stratified analysis, women who drank tea had a lower risk of osteoporosis than women who never drank any. Compared with the NTC group, the multivariate-adjusted HR (aHR) for the LTC group was 0.86 (95% *CI* 0.78–0.95), and the aHR for the HTC group was 0.88 (95% *CI* 0.80–0.97). For the men stratum, the same analyses were not statistically significant. Compared with the NTC group, the aHR for the LTC group was 1.03 (95% *CI* 0.81–1.32), and the aHR for the HTC group was 0.82 (95% *CI* 0.66–1.03). The age-stratified analysis showed that tea consumption was negatively associated with osteoporosis in the middle-aged stratum (45 to 59 years). Compared with the NTC group, the aHR for the LTC and the HTC groups were 0.85 (95% *CI* 0.74–0.96), and 0.79 (95% *CI* 0.69–0.90), respectively. However, there was no significant association in the old-aged stratum (60 to 74 years). Compared with the NTC group, the aHR for the LTC and HTC groups were 0.90 (95% *CI* 0.79–1.02) and 0.94 (95% *CI* 0.83–1.05), respectively.

Risk of hip fracture

The number of hip-fracture events and adjusted HRs for hip fracture for the three tea-consumption groups is presented in Table 4. During the follow-up period, 454 cases

Table 1 Baseline characteristics of women ($n = 25,775$) by tea-consumption group

Variable	No tea consumption ($n = 12,012$)	Low tea consumption ($n = 6573$)	High tea consumption ($n = 7190$)	p value[a]
Age, years (mean ± SD)	57.8 ± 8.1	54.1 ± 7.0	54.6 ± 7.2	< . 0001
BMI, kg/m^2 (mean ± SD)	24.4 ± 3.8	24.7 ± 3.7	25.1 ± 3.8	< . 0001
Physical activity, *n* (%)				< . 0001
No physical activity	4462 (37.1)	2152 (32.7)	2579 (35.9)	
Low physical activity	2738 (22.8)	2041 (31.1)	1866 (25.9)	
High physical activity	4812 (40.1)	2380 (36.2)	2745 (38.2)	
Smoking status, *n* (%)				< . 0001
Non-smoker	11,406 (95.0)	6135 (93.3)	6513 (90.6)	
Ex-smoker	99 (0.8)	87 (1.3)	118 (1.6)	
Current smoker	507 (4.2)	351 (1.6)	559 (7.8)	
Alcohol consumption, *n* (%)				< .0001
Non-drinker	11,318 (94.2)	5962 (90.7)	6388 (88.8)	
Ex-drinker	107 (0.9)	81 (1.2)	101 (1.4)	
Current drinker	587 (4.9)	530 (8.1)	701 (9.8)	
Education, *n* (%)				< . 0001
Lower	6634 (55.2)	2253 (34.3)	2797 (38.9)	
Median	4312 (35.9)	3318 (50.5)	3518 (48.9)	
Higher	1066 (8.9)	1002 (15.2)	875 (12.2)	
Diabetes, *n* (%)	1184 (9.9)	455 (6.9)	634 (8.8)	< .0001
Hypertension, *n* (%)	2957 (24.6)	1290 (19.6)	1476 (20.5)	< .0001
Hyperlipidemia, *n* (%)	1912 (15.9)	879 (13.4)	979 (13.6)	< .0001
Coronary heart disease, *n* (%)	971 (8.1)	332 (5.0)	388 (5.4)	< .0001
Stroke, *n* (%)	356 (3.0)	115 (1.8)	113 (1.6)	< .0001
Cancer, *n* (%)	282 (2.4)	105 (1.6)	112 (1.6)	< .0001

BMI = body mass index, *SD* = standard deviation

[a]*p* values are based on chi-square testing or analysis of variance

of hip fracture were identified. Compared with the NTC group, the HTC group had a reduced risk of hip fracture (aHR = 0.69, 95% *CI* 0.55–0.86), but the LTC-NTC difference in such risk was non-significant (*aHR* = 0.85, 95% *CI* 0.67–1.08).

Discussion

The results of this population-based longitudinal follow-up study suggest that individuals who drink tea are at a lower risk of osteoporosis than those who do not. To the best of our knowledge, this is the first large-scale cohort study to show that the negative association between tea consumption and osteoporosis is more prominent in the middle-aged population (aged 45 to 59 years) than among the elderly (aged 60 to 74 years). In addition, we found that people who reported high tea consumption had a reduced risk of hip fracture compared with those who reported consuming no tea.

Prior studies, which mainly enrolled postmenopausal women, demonstrated that tea consumption might reduce osteoporosis risk [10, 11, 23, 24]. In contrast, a limited number of studies investigating the effect of tea consumption on osteoporosis among men reported a lack of protective effect [18, 25, 26]. Similar to previous studies, our study found that tea consumption was associated with a lower risk of osteoporosis in women, and there was a lack of significant association between tea consumption and osteoporosis in men. Moreover, while few previous studies have evaluated the protective effect of tea consumption against osteoporosis in the middle-aged population, our study showed that tea's benefits were more prominent among middle-aged population (aged 45 to 59 years) than elderly people. Such findings could mean that policies encouraging regular tea consumption among middle-aged people (aged 45 to 59 years) might help reduce their risk of osteoporosis. However, the explanation for a more beneficial response in young adults is unclear. Further studies are needed to elucidate these findings.

Previous studies on the association between tea consumption and hip fracture have yielded inconclusive results. Myers et al. showed that higher tea consumption had a protective effect against osteoporotic fractures in women in Australia aged 75 and above [15]. In contrast, Chen et al.

Table 2 Baseline characteristics of men ($n = 16{,}967$) by tea-consumption group

Variable	No tea consumption ($n = 5499$)	Low tea consumption ($n = 4635$)	High tea consumption ($n = 6833$)	p value[a]
Age, years (mean ± SD)	59.0 ± 8.6	55.7 ± 7.8	57.2 ± 8.1	< .0001
BMI, kg/m^2 (mean ± SD)	24.8 ± 3.5	25.4 ± 3.3	25.5 ± 3.3	< .0001
Physical activity, *n* (%)				< .0001
No physical activity	1 802 (32.8)	1 269 (27.4)	1 925 (28.2)	
Low physical activity	1 291 (23.5)	1 480 (31.9)	1 743 (25.5)	
High physical activity	2 406 (43.7)	1 886 (40.7)	3 165 (46.3)	
Smoking status, *n* (%)				< .0001
Non-smoker	2 831 (51.5)	2 129 (45.9)	2 478 (36.3)	
Ex-smoker	860 (15.6)	945 (20.4)	1 265 (18.5)	
Current smoker	1 808 (32.9)	1 561 (33.7)	3 090 (45.2)	
Alcohol consumption, *n* (%)				< .0001
Non-drinker	3 364 (61.2)	2 452 (52.9)	3 590 (25.5)	
Ex-drinker	436 (7.9)	343 (7.4)	561 (8.2)	
Current drinker	1 699 (30.9)	1 840 (39.7)	2 682 (39.3)	
Education, *n* (%)				< .0001
Lower	2 134 (38.8)	999 (25.6)	1 828 (26.8)	
Median	2 423 (44.1)	2 458 (53.0)	3 555 (52.0)	
Higher	942 (17.1)	1 178 (25.4)	1 450 (21.2)	
Diabetes, *n* (%)	611 (11.1)	496 (10.7)	822 (12.0)	0.0680
Hypertension, *n* (%)	1 603 (29.2)	1 180 (25.5)	1 816 (26.6)	< .0001
Hyperlipidemia, *n* (%)	873 (15.9)	653 (14.1)	1 093 (16.0)	0.0117
Coronary heart disease, *n* (%)	498 (9.1)	342 (7.4)	524 (7.7)	0.0029
Stroke, *n* (%)	324 (5.9)	137 (3.0)	248 (3.6)	< .0001
Cancer, *n* (%)	129 (2.4)	88 (1.9)	127 (1.9)	0.1240

BMI body mass index, *SD* standard deviation

[a]*p* values are based on chi-square testing or analysis of variance

reported no significant association between tea consumption and hip fracture in postmenopausal women in the USA aged 50 to 79 [10]. However, these two studies may have limited generalizability, as they only recruited postmenopausal women who were willing to be followed up in clinical centers. Our study used a representative sample from a community-based screening program and showed that high tea consumption was associated with a lower risk of hip fracture (Table 4, *aHR* = 0.69, 95% *CI* 0.55–0.86).

Excessive oxidative stress or chronic inflammation can accelerate bone resorption and osteoporosis [6, 27]. Tea-extract flavonoids have antioxidant and anti-inflammatory properties and have been demonstrated to protect against bone loss and reduce the risk of osteoporosis [4, 28]. In ovariectomized animal models, green tea extract and black tea extract have been suggested to diminish the expression of the osteoclast-specific gene and proteins and inhibit the osteoclastogenesis, with an effective improvement of osteoporosis [8, 9]. Based on previous experimental evidence, then, our findings that tea consumption had a protective effect against osteoporosis are biologically plausible. However, many types of tea contain caffeine [29]. Previous studies have suggested that high caffeine intake accelerates bone loss in elderly women and is associated with an increased fracture risk [12, 13]. Therefore, further study is needed to investigate the optimal tea consumption to protect against osteoporosis.

While low BMD is one major measurable determinant of the risk of osteoporotic fractures, risk factors for hip fractures other than low BMD include those that affect the odds of trauma (e.g., fall) occurring, including neuromuscular impairment, cognitive impairment, physical inactivity, and use of sedative medications [30]. Previous studies have shown that tea and tea-extract flavonoids could improve self-reported alertness, are associated with a lower risk of cognitive impairment [31], and help maintain skeletal muscle health [32]. Consequently, they could decrease fall-related fragility hip fractures.

The key strength of this study was its population-based design with long-term follow-up. In addition, our study at baseline recruited members of two groups — males and the middle-aged — that are relatively under-studied in the context of osteoporosis and hip fracture. Nevertheless, this observational study design is not able to establish a causal

Table 3 Risk of osteoporosis (diagnosed based on BMD) by tea-consumption group, sex strata, and age strata

Variable	No tea consumption	Low tea consumption	High tea consumption
All participants (*N* = 42,742)			
Osteoporosis events, *N*	1801	675	802
Risk per 1000 person-years (95% *CI*)	13.49 (12.88–14.13)	7.69 (7.12–8.29)	7.26 (6.77–7.78)
Age and sex-adjusted HR (95% *CI*)	1.00	0.86 (0.78– 0.94)[a]	0.84 (0.77– 0.91)[a]
Multivariate-adjusted HR[b] (95% *CI*)	1.00	0.88 (0.80–0.96)[a]	0.87 (0.80–0.94)[a]
Men (*n* = 16,967)			
Osteoporosis events, *n*	178	112	150
Age-adjusted HR (95% *CI*)	1.00	0.98 (0.77– 1.24)	0.77 (0.62– 0.96)[a]
Multivariate-adjusted HR[b] (95% *CI*)	1.00	1.03 (0.81–1.32)	0.82 (0.66–1.03)
Women (*n* = 25,775)			
Osteoporosis events, *n*	1623	563	652
Age-adjusted HR (95% *CI*)	1.00	0.84 (0.76– 0.92)[a]	0.85 (0.78– 0.94)[a]
Multivariate-adjusted HR[b] (95% *CI*)	1.00	0.86 (0.78–0.95) [a]	0.88 (0.80–0.97)[a]
Age 45 to 59 (*n* = 28,629)			
Osteoporosis events, *n*	658	371	385
Age and sex-adjusted HR (95% *CI*)	1.00	0.82 (0.72– 0.94)[a]	0.76 (0.67– 0.86)[a]
Multivariate-adjusted HR[b] (95% *CI*)	1.00	0.85 (0.74–0.96)[a]	0.79 (0.69–0.90)[a]
Age 60 to 74 (*n* = 14,113)			
Osteoporosis events, *n*	1143	304	417
Age and sex-adjusted HR (95% *CI*)	1.00	0.88 (0.78– 1.00)	0.91 (0.81– 1.02)
Multivariate-adjusted HR[b] (95% *CI*)	1.00	0.90 (0.79–1.02)	0.94 (0.83–1.05)

CI confidence interval, *HR* hazard ratio, *BMI* = ody mass index

[a]$p < 0.05$

[b]Multivariate Cox proportional-hazard regression model with adjustments for sex, age, body-mass index, physical activity, smoking status, drinking status, education, diabetes, hypertension, hyperlipidemia, coronary heart disease, stroke, and cancer

Table 4 Risk of hip fracture by tea-consumption group

Variable	No tea consumption (*n* = 17,511)	Low tea consumption (*n* = 11,208)	High tea consumption (*n* = 14,023)
Hip fracture events, *n*	265	82	107
Risk per 1000 person-year (95% *CI*)	2.91 (2.57–3.28)	1.44 (1.45–1.79)	1.52 (1.24–1.83)
Age and sex-adjusted HR (95% *CI*)	1.00	0.79 (0.62–0.99)[a]	0.68 (0.54–0.85)[a]
Multivariate-adjusted HR[b] (95% *CI*)	1.00	0.85 (0.67–1.08)	0.69 (0.55–0.86)[a]

CI confidence interval, *HR* hazard ratio

[a]$p < 0.05$

[b]Multivariate Cox proportional-hazard regression model with adjustments for sex, age, body-mass index, physical activity, smoking status, drinking status, education, diabetes, hypertension, hyperlipidemia, coronary heart disease, stroke, and cancer

relationship. Moreover, there are several limitations of this study that should be acknowledged. First, the eating habits questionnaire used in KCIS recorded the frequency of tea consumption self-reported by screening participants without measuring the accurate dose of tea intake. In addition, detailed information about vitamin D and calcium intake is not available in the database. These factors were not included in the analysis. Thus, it is possible that residual confounding of the association between tea consumption and osteoporosis may have been present. Moreover, the benefit of tea consumption on bone health could be confounded by other nutritional factors, lifestyle factors, or substitute beverages such as coffee. Nevertheless, it has been suggested that caffeine generally plays a minor role in bone health [33].

Second, the diagnoses of osteoporosis, hip fractures, and medical comorbidities were determined using the ICD codes from the NHIRD, which could raise concerns about their accuracy. However, the NHI Bureau's audit committees

randomly sample its claim data and regularly review medical records to verify diagnostic accuracy, as well as the quality of care. Consequently, the NHIRD is a well-established research database, and the validity of its data has been demonstrated by independent studies [34]. However, since the DXA scanners used in the clinics of the NHI system were not all the same model, and the DXA scanners were not cross-validated, there may be measurement errors of BMD.

Third, because of an insufficient number of hip fracture events, subgroup analysis of the association between tea consumption of hip fracture was not performed. Further research on the impact of tea consumption on the risk of hip fracture stratified by age and sex is suggested. Fourth, the ethnicity of the participants was Taiwanese, and the results of this study may not be generalized to other ethnic groups.

In conclusion, the present population-based longitudinal follow-up study has shown that tea consumption was associated with a reduced risk of osteoporosis. Moreover, people with high tea consumption were at a lower risk of hip fracture. However, further studies are needed to investigate the mechanisms that underlie these findings.

Author contribution YPH, LSC, and SLP designed the research; YPH, SHF, YSL, and SLP conducted the research; YPH and SLP analyzed the data; YPH, LSC, SHF, YSL, and SLP wrote the manuscript; and YPH, LSC, SHF, YSL, and SLP had primary responsibility for final content. All the authors read and approved the final manuscript.

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Data availability The data generated and analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval For this type of study formal consent is not required.

Informed consent Not applicable.

Consent for publication Consent for submission and publication has been received from all the authors.

Conflict of interest None.

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